PB84-195353

Human Exposure Assessment: Background Concepts, Purpose, and Overview of the Washington, DC - Denver, Colorado Field Studies

(U.S.) Environmental Monitoring Systems Lab.
Research Triangle Park, NC

May 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-195353

EPA-600/D-84-131
May 1984

Human Exposure Assessment: Background Concepts, Purpose, and Overview of the Washington, D.C. - Denver, Colorado Field Studies

by

Gerald G. Akland
U. S. Environmental Protection Agency
Research Triangle Park, N. C. 27711

Wayne R. Ott, and Lance A. Wallace
U. S. Environmental Protection Agency
Washington, D. C. 20460

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/D-84-131	2.	3. RECIPIENT'S ACCESSION NO. PB84 195353
4. TITLE AND SUBTITLE HUMAN EXPOSURE ASSESSMENT: BACKGROUND CONCEPTS, PURPOSE AND OVERVIEW OF THE WASHINGTON, D. C. - DENVER, COLORADO FIELD STUDIES		5. REPORT DATE May 1984 6. PERFORMING ORGANIZATION CODE EMSL/RTP
7. AUTHOR(S) Gerald G. Akland,* Wayne R. Ott,* and Lance A. Wallace**		8. PERFORMING ORGANIZATION REPORT NO. #605
9. PERFORMING ORGANIZATION NAME AND ADDRESS *U.S. Environmental Protection Agency Research Triangle Park, NC 27711 **U.S. Environmental Protection Agency Washington, DC 20460		10. PROGRAM ELEMENT NO. A114 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Monitoring Systems Laboratory Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED conference proceedings 14. SPONSORING AGENCY CODE EPA/600/08

15. SUPPLEMENTARY NOTES

16. ABSTRACT

In the past, no scientifically valid approach for determining the exposures of an urban population to a pollutant was available. Recently, EPA successfully field tested two separate but complementary approaches for determining population exposures to air pollution: (a) direct measurement of exposure profiles of a representative random sample of the population with personal exposure monitors, and (b) an indirect approach which combines human activity pattern data with microenvironmental concentration data to estimate exposure profiles. In the winter of 1982-83, the two approaches were field tested. This effort provides a rich human exposure data base and a methodology that can be applied to other pollutants and other urban areas.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Exposure Assessment Carbon Monoxide		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	19
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Abstract

In the past, no scientifically valid approach for determining the exposures of an urban population to a pollutant was available. Recently, EPA successfully field tested two separate but complementary approaches for determining population exposures to air pollution: (a) direct measurement of exposure profiles of a representative random sample of the population with personal exposure monitors, and (b) an indirect approach which combines human activity pattern data with microenvironmental concentration data to estimate exposure profiles. In the winter of 1982-1983, the two approaches were field tested. This effort provides a rich human exposure data base and a methodology that can be applied to other pollutants and other urban areas.

Human Exposure Assessment: Background, Concepts, Purpose, and Overview of the Washington, D.C. - Denver, Colorado Field Studies

INTRODUCTION

Traditionally, compliance with the National Ambient Air Quality Standards (NAAQS) has been judged using data from fixed monitoring stations. It was assumed that fixed site monitors were adequate for the purpose of estimating pollutant exposures to the public.

In recent years, considerable interest has been focused on the problem of determining, with known confidence, the actual exposures of the population to environmental pollution. This has paralleled the needs of the U. S. Environmental Protection Agency (U.S.E.P.A.) to improve risk assessment methodology of which human exposure assessment is an integral part (Figure 1). Considerable research effort has been devoted to schemes for calculating human "exposures," even though such calculations often rely upon the limited data that are available from fixed air monitoring stations as indicated in a literature review of this topic.[1] Despite these past efforts to estimate exposures, the U.S. EPA possesses very few reliable data on actual exposures. Little is known about an individual's diurnal and day to day variation in exposure, or about the variation from person to person of the exposure to a given air pollutant in a particular urban area, or about the frequency distribution of the maximum daily exposures of any of its subpopulations.

Previous efforts to estimate "potential exposures" typically were based on the pollutant concentrations likely to occur at residential locations. Demographic data consisting of the residential locations of individuals are merged with the nearest fixed site concentrations, as described in papers by Horie and Stern[2] and Briggs, Throgmorton and Karoffa.[3] Such an approach assumes that a stationary fixed site monitor located outside can provide a measure, directly or indirectly, of an individual's actual exposure. There are, however, many reported discrepancies between actual and estimated exposures, as indicated in the literature on this topic,[1,4] and a number of factors contribute to these discrepancies (see Table I). Another approach was to model concentrations at a point in space and time and adjust for indoor and other factors, and several exposure models of this type have been developed.[5-7]

In the last decade, a number of new personal exposure monitors (PEMS) have been developed and refined, as indicated in a review of this technology by Wallace and Ott.[8] The availability of these new instruments suggested an opportunity to measure population exposure directly at levels found in the ambient atmosphere. Without these new instruments, the present investigations would not have been possible.

A pilot study to measure personal exposure using PEM's was undertaken by Ziskind[9,10] in Los Angeles in 1980. The objective was to determine the feasibility of using PEM's by the general public. The results showed that the PEM's could be used in field studies with relative ease and the resulting exposure levels could be associated with microenvironments and activity patterns of the individuals.

Analysis of the pilot results indicated that a methodology could be tested on a population living in a well specified area to provide estimates of the distribution of exposure for a selected pollutant.

APPROACHES FOR DETERMINING EXPOSURES

Before formulating the details of the study design, it is important to note that two alternative conceptual approaches exist for determining the exposures of the population to air pollution: field measurement of a representative population with PEM instruments (direct approach); and computation using field data collection of activity patterns and measuring concentration levels within microenvironments (indirect approach). These two approaches are discussed in papers by Duan[11,12] and others.[1,13]

Direct Approach

If it were possible to give everyone in the city a PEM instrument, and if they were instructed to carry the instrument throughout the day while they engaged in their normal activities, and if the concentrations experienced were automatically recorded within the instrument, then it would be possible to collect all the instruments at the end of a given time and read the self-contained exposure record for every person in the city. If each person's highest 8-hour exposure were plotted on a histogram, then the resulting plot might look like Figure 2. Here, the sum of the shaded areas to the right of 9 ppm on the curve represents the proportion of the population above 9 ppm. If the study were conducted for a full year, one would be able to describe the population exposures fully and completely, compare the results with existing standards and describe exposures to critical subpopulations thought to be in especially high risk categories. Obviously, such a research investigation would be costly and would create serious logistical problems in the distribution and collection of PEM instruments.

A less costly approach is to follow the precedent established by the social scientists to sample a smaller, representative population of the urban area. If the population is chosen in such a manner that it includes disproportionately large subpopulations of special interest in the study, then it would be possible to examine the frequency distribution of exposures with known precision, for both the overall population, as well as for particular subpopulations of interest (e.g., infants, persons with a history of heart problems, or persons in high-risk occupations). A further simplification is to sample only during periods of maximum expected concentration levels, since the highest levels of a pollutant are of greatest concern. To conduct a study of this type, the population must be chosen according to very specific procedures. The final result of such an approach is a frequency distribution of the population living in the study area exposed to various concentration levels (Figure 2).

Indirect Approach

This approach combines data on the times that people spend in selected microenvironments with estimates of the concentrations likely to be experienced in these microenvironments in order to compute the resulting exposures of the population. Estimation of the average exposure of a

population, if the data for both activity patterns and microenvironmental concentrations are available, is computationally relatively easy. Estimation of the frequency distribution of exposures is somewhat more difficult computationally, since combining mixtures of distributions is required. Furthermore, detailed measurements within microenvironments are required in order to model the concentration levels with suitable accuracy.

In its simplest form, the problem is to compute the integrated exposure as the sum of the individual products of the concentration encountered by a person in a microenvironment and the time the person spends there. From the integrated exposure, it is possible to compute the average exposure for any averaging period. That is, if the concentration within microenvironment j is assumed to be constant during the period that person i occupies microenvironment j, then the integrated exposure E_i for person i will be the sum of the product of the concentration in each microenvironment and the time that person i spends there:

$$E_i = \sum_{j=1}^{J} C_j \, t_{ij}$$

Where E_i = integrated exposure of person i over the time period of interest

C_j = concentration experienced in microenvironment j

t_{ij} = time spent by person in microenvironment j

J = total number of microenvironments occupied by person i over the time period of interest

To compute the integrated exposure E_i for person i, it obviously is necessary to estimate both C_j and t_{ij}.

For pollutants of interest, scientifically defensible microenvironments must be identified, statistically characterized, related to sources, and described in a stochastic-deterministic submodel. The submodels must then be combined in an activity-pattern-microenvironmental computational approach in order to calculate exposures for each person over a 24-hour period. The NEM model[5] and SHAPE model[6,7] have employed many of these concepts in their development. These models are capable of generating a predicted frequency distribution of exposures similar to Figure 2 for a city based on ambient data and other information from the city. Until the field studies described in the present paper were completed, however, no field data were available to validate these models.

In addition to being more economical than the direct exposure approach, a validated model would permit the Agency to predict future exposures and dose distributions for the population of a city in response to a variety of different assumed emission control strategies and assumptions. For example, changes in vehicular emissions may be related to statistical parameters of the concentration distributions for each microenvironment which contains motor vehicles as its major source (parking garages, roadways, buildings with attached garages). Similarly, changes in the emissions of

gas stoves may be related to the statistical parameters that describe the concentration distributions for residences with gas stoves. Thus, the impact upon exposure frequency distributions of any of a variety of regulatory strategies and scenarios can be predicted by simply running the computer program with the assumption incorporated in the input parameters. Finally, the impact of changes in human activity patterns on population exposures also can be predicted with relative ease. For example, if we assume that average vehicular home-to-work commute trip times in the city decrease by 40%, the effect of this change on the frequency distribution of exposures can be computed on a single computer run.

Relevance to Indoor Air Pollution

The contribution of indoor air pollution to an individual's total exposure is clear, since time-budget surveys[14,15] have shown that most of us are at home more than 16 hours per day, with other indoor time divided between the workplace, commercial and public buildings, and transportation.[16] The relationships among personal exposures, indoor air, and ambient air are unclear. These relationships need to be understood for each pollutant in order to minimize the cost of control and assessing risk. The following discussion of EPA's investigation of CO exposure in two cities is but one source of information which will help clarify these interrelationships. Future studies of other pollutants and cities are required before the Agency can properly assess risks to populations for the numerous compounds and elements required for regulation. The following study is offered as an example by which present and future exposure assessment methodologies may be judged. Indeed, CO is a model pollutant for determining human exposures, since (1) its health effects are understood, (2) suitable PEM instruments are available, (3) human activity-exposure models have been developed, (4) exposure-dose models relating CO to blood carboxyhemoglobin are available, (5) its sources are known and understood, and (6) NAAQS for CO have been promulgated.

HUMAN EXPOSURE FIELD STUDIES: WINTER 1982-83

In the winter of 1982-83, EPA conducted large-scale urban field studies to develop and test methodologies for determining, with known accuracy, the exposures to CO of the population of a city. The direct measurement approach for determining exposure profiles was carried out in both Denver and Washington, D.C., and the indirect approach using concentration microenvironments was carried out as a comparison study in Washington, D.C. This study met a variety of objectives and tested a number of hypotheses (Table II).

Direct Measurement

The two cities chosen for the direct measurement field study -- Denver and Washington, D.C. -- were selected because they differ in (1) elevation, (2) past CO levels based on fixed site data, (3) geographical area, (4) administrative complexities (single or multiple state), and (5) commuter patterns.

In both cities, a screener was administered by telephoning a representative random sample of the population -- approximately 3,200 households in Denver and 5,800 households in Washington, D.C., were called. During the screening process, respondents were asked about their smoking habits, commute times, and other factors of importance. Data from the screener survey made it possible subsequently to create a stratified random sample of individuals with particular characteristics of interest than are present in a purely random sample. For example, only nonsmokers were selected in the final sample, and persons who commuted long distances were more heavily sampled than were those who commuted short distances.

The survey was made possible with a specially designed PEM capable of recording CO concentrations with a time resolution of 1 minute or less and recording average CO concentrations on a built-in data logger.[17] The approach was patterned after the time budget studies of Szalai.[14] The interviewer visited the respondent and left off a calibrated PEM with instructions for its use and a diary. The respondent carried the PEM recording each change of location and activity in the diary and depressing the data logging button at appropriate times. A questionnaire also was administered to obtain detailed information about the respondent's home, workplace, and commute habits. Details of the survey are presented in the final report on Denver by Johnson[18] and the final report on Washington, D.C., by Hartwell *et al.*[19] Many important findings are summarized in papers by Johnson *et al.*,[20] and Hartwell *et al.*[21] The survey follows an EPA research plan developed by Ott, Blacker, and Akland.[22]

As indicated earlier, one goal of this exposure methodology was to determine the frequency distribution of exposures of the nonsmoking population, represented hypothetically by the histogram of Figure 2. The actual observed cumulative frequency distributions of maximum 8-hour daily exposures for the two cities can be plotted on logarithmic probability paper for ease of presentation (Figure 3). The Denver field study yielded 900 24-hour exposure profiles (450 persons, 2 days each), and the Washington, D.C., field study yielded 712 24-hour exposure profiles (712 persons, 1 day each). The effect of weighting the distribution to account for the sample design can be seen in the distribution shown for Denver. The observed exposure distribution in Denver yielded levels approximately twice as high as the levels found in Washington, D.C., and concentrations at the Denver fixed stations also were about twice those observed in Washington, D.C. Although the median CO 8-hour daily maximum exposure (3.5 ppm, weighted; 3.8 ppm unweighted) was nearly identical to the median 8-hour daily maximum observed at the Denver fixed stations (3.7 ppm, composite of all stations), the slope of the personal exposure distribution was much greater than the slope of the composite fixed station readings. For example, in Denver only 3% of the 8-hour daily maximum fixed station readings were above 9 ppm, but 10.7% of 8-hour maximum daily CO exposures were above 9 ppm. The greater slope is due to the greater person-to-person variability in exposures, which, in turn, is due mainly to differences in activities of the population. As indicated in the paper by Wallace *et al.*,[23] the levels of CO observed in the breaths of respondents in Denver also were higher than those in the breaths of Washington, D.C., respondents.

Indirect Estimation

EPA conducted several preliminary field studies to determine the feasibility and effectiveness of monitoring selected microenvironments for use in estimating exposure profiles indirectly. Early methodological studies were conducted on commercial settings[24,25] and in Los Angeles, Denver, Phoenix, and Stamford.[26,27]

During the winter of 1982-83, EPA also conducted a field application of the indirect monitoring approach to exposure estimation in Washington, D.C.[28] It concentrated on the commuting microenvironment, because earlier studies identified this microenvironment type as the single most important one relative to the total population exposure. This study was facilitated by the availability of activity pattern information for the study area which was collected as part of the direct approach discussed above.

It was observed that typical CO exposures ranged from 8-13 ppm for the average automobile commute. In contrast, bus or train commuters typically received less exposure to CO. These values can be interpreted according to Table III which provides the area average CO level for the morning commute period (0700-0900) and afternoon commute period (1600-1800) for the months of January and February. It can be seen that commuting will add on the average 8-9 ppm to a person's exposure for the time of the commute. This is consistent with results observed in Denver, Colorado, and Los Angeles, California, during the winter of 1981[26,27] and it is consistent with the 5.1 ppm average CO concentration observed during the field study for all (592) participants who utilized a car for transit activities.[19]

Factors influencing these concentrations (in descending order of importance) were identified as (1) link-to-link variability, (2) day-to-day variability, and (3) time of day. In addition, vehicle speed could contribute up to 40% of the variability. Accuracy and monitor imprecision were the least important sources of variation.[28]

The resulting data from this experiment will be used to develop a predictive commuter exposure model for CO, which will utilize traffic count, traffic mix, and vehicle age. Results of this exposure model will be compared with direct measures of personal exposure.

CONCLUSIONS

EPA's air monitoring research program has undertaken an ambitious research effort to better estimate population exposures to air pollutants. Previously, a large body of literature had accumulated showing that fixed monitoring stations do not necessarily reflect the concentrations with which people come into actual contact in their daily lives. Until the present investigations, however, no data were available for determining the extent of agreement or disagreement between fixed stations and actual exposures of the sample of the population. In these studies, a new methodology has been developed and successfully field tested in two U. S. cities. This methodology combines statistical survey design techniques from the social sciences with miniaturized automated PEM's in order to

generate exposure profiles for a representative population sample. The result is a rich data base that can be used to (1) assess the risk of a pollutant to public health, (2) interpret and understand the data collected by conventional fixed air monitoring networks, (3) select fixed monitoring stations that better reflect average population exposures, (4) allow investigators to better assess the impact of alternative regulatory strategies, and (5) permit investigators to develop models for predicting future exposure distributions in response to changes in urban form, human activities, and population growth.

A similar research project called the Total Exposure Assessment Methodology (TEAM) has been undertaken for multi-media exposures to a variety of pollutants.[30] These two major exposure programs will provide results to both the scientific and regulatory communities for assessing risks to environmental polluants and need for changes in control strategies. Eventually the constraints of the two approaches for exposure assessment will be better understood and quantified so that the appropriate approach can be applied to obtain exposure assessments within specified limits of confidence.

This article has not been subjected to Agency review and does not necessarily reflect the views of the Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

References

1. W. R. Ott, "Concepts of Human Exposure to Air Pollution," Environment International, Vol. 7, pp. 179-196, 1982.

2. Y. Horie and A. C. Stern, "Analysis of Population Exposure to Air Pollution in the New York-New Jersey-Connecticut Tri-State Region," Report No. EPA-450/3-76-027, U.S. Environmental Protection Agency, Research Triangle Park, N. C., 1976.

3. T. Briggs, J. Throgmorton, and M. Karaffa, "Air Quality Assessment of Particulate Emissions from Diesel-Powered Vehicles," Report No. EPA-450/3-78-038, U.S. Environmental Protection Agency, Research Triangle Park, N. C., 1978.

4. J. D. Spengler and M. L. Soczek, "Evidence for Improved Ambient Air Quality and the Need for Personal Exposure Research," Proceedings of the Third Annual National Symposium on Recent Advances of Pollutant Monitoring of Ambient Air and Stationary Sources, U. S. Environmental Protection Agency, Research Triangle Park, N. C., 1978.

5. T. Johnson and R. A. Paul, "The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide," U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Strategies and Air Standards Division, Research Triangle Park, N. C., April 1982.

6. W. R. Ott, "Exposure Estimates Based on Computer Generated Activity Patterns," Paper No. 81-51.6, presented at the 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, June 21-26, 1981.

7. W. R. Ott, "Computer Simulation of Human Air Pollution Exposures to Carbon Monoxide," submitted for publication to the Journal of the Air Pollution Control Association, 1984.

8. L. A. Wallace and W. R. Ott, "Personal Monitors: A State-of-the-Art Survey," Journal of the Air Pollution Control Association, Vol. 32, June 1982, pp. 601-610.

9. R. A. Ziskind, "Pilot Field Study - Carbon Monoxide Exposure Monitoring in the General Population," final draft report prepared under EPA Contract No. 68-02-3412, Science Applications, Inc., Los Angeles, CA, October 27, 1981.

10. R. A. Ziskind, K. Fite, and D. T. Mage, "Pilot Field Study: Carbon Monoxide Exposure Monitoring in the General Population," Environment International, Vol. 8, pp. 283-293, 1982.

11. N. Duan, "Microenvironment Types: A Model for Human Exposure to Air Pollution," SIMS Technical Report No. 47, Stanford, CA, May 1981.

12. N. Duan, "Models for Human Exposure to Air Pollution," Environment International, Vol. 8, pp. 305-309, 1982.

13. J. L. Repace, W. R. Ott, and L. A. Wallace, "Total Human Exposure to Air Pollution," Paper No. 80-61.6 presented at the 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Canada, June 1980.

14. A. Szalai, The Use of Time: Daily Activities of Urban and Suburban Populations in Twelve Countries, Mouton, The Hague, Paris, 1972.

15. F. S. Chapin, Jr., Human Activity Patterns in the City: Things People Do in Time and Space, John Wiley & Sons, New York 1974.

16. W. R. Ott, "Human Activity Patterns: A review of the Literature for Air Pollution Exposure Extimation," U.S. Environmental Protection Agency, draft report, May 24, 1982.

17. W. R. Ott, C. Williams, C. Rodes, R. Drago, and F. Burmann, "Application of Microprocessors to Data Logging Problems in Air Pollution Exposure Field Studies," Paper No. 121.2 presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, CA, June 24-29, 1984.

18. T. Johnson, "A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado," report by PEDCo Environmental, Inc., to the U. S. Environmental Protection Agency, Research Triangle Park, N. C., December 1983.

19. T. D. Hartwell, et al., "Study of Carbon Monoxide Exposure of Residents of Washington, D. C., and Denver, Colorado," report by Research Triangle Institute to the U.S. Environmental Protection Agency, Research Triangle Park, N. C., January 1984, Parts I and II.

20. T. Johnson, "A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado," Paper No. 121.3, presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, CA, June 24-29, 1984.

21. T. D. Hartwell, et al., "A Study of Carbon Monoxide Exposure of the Residents in Washington, D. C.," Paper No. 121.4 presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, CA, June 24-29, 1984.

22. W. Ott, S. Blacker, and G. G. Akland, "A Research Plan for Population Exposure Monitoring Methodology: Vehicular Air Pollutants," U.S. Environmental Protection Agency, Washington, D.C., November 16, 1981.

23. L. A. Wallace, W. R. Ott, D. T. Mage, and J. Thomas, "Alveolar CO Measurements of 1,000 Residents of Denver and Washington, D.C. -- A Comparison with Preceding Personal Exposures," Paper No. 121.5 presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, CA, June 24-29, 1984.

24. P. G. Flachsbart and W. R. Ott, "Field Surveys of Carbon Monoxide in Commercial Settings Using Personal Exposure Monitors," Report No. EPA-600/4-84-019, U.S. Environmental Protection Agency, Office of Research and Development, February 1984.

25. W. R. Ott and P. Flachsbart, "Measurement of Carbon Monoxide in Indoor and Outdoor Locations Using Personal Exposure Monitors," Environment International, Vol. 8, 1982, pp. 295-304.

26. D. M. Holland and D. T. Mage, "Carbon Monoxide Concentrations in Four U.S. Cities During the Winter of 1981," draft report, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Research Triangle Park, N. C., 1983.

27. D. M. Holland, "Carbon Monoxide Levels in Microenvironment Types of Four U.S. Cities," submitted to Environment International, 1983.

28. G. A. Mack, P. A. Flachsbart, C. E. Rodes, J. E. Howes, G. G. Akland, and H. B. Sauls, "Microenvironmental Approach to Estimation of Carbon Monoxide Exposures to Commuters," submitted for publication to the Journal of the Air Pollution Control Association, March 1984.

29. P. G. Flachsbart, "Field Survey Procedures for Measuring Carbon Monoxide Exposures of Commuters in the Washington Metropolitan Area," report under Cooperative Agreement No. CR-810344-01-0, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Research Triangle Park, N. C., September 8, 1982.

30. E. D. Pellizzari, et al. "Total Exposure Assessment Methodology (TEAM) Study: Phase II -- Draft Work Plan, Parts I, II, and III, U. S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., 1981.

Table I. Primary factors influencing ambient concentrations and personal exposures to air pollutants

Factor	Ambient	Personal
Emission Factors	Outdoor Point and Area Sources	Outdoor Plus Diverse Indoor Sources with Pollutant Interactions
Human Activity Patterns	No Major Effect	Major Effect
Physical Scale	10m-1000m	0-10m
Exposure Pathways	Ambient Air	Ambient Air, Indoor Sources, and Ventilation Systems
Microenvironments	Outdoor	Indoor; Outdoor and In-Transit

Table II. Study Objectives and Hypotheses of Interest

- Develop Methodology to Estimate Population Exposure to CO for an Urban Area.
- Obtain Exposure Estimates and Relate to Fixed Site Measurements.
- Develop Methodology for Selecting Relevant Microenvironments.
- Develop Methodology for Using PEM's for Analysis of COHb in Breath.
- Are CO Exposures Higher for Commuters than for Noncommuters?
- Do Persons Living in Homes with Unvented Gas Appliances have Higher CO Exposures?
- Can Activity Patterns Explain Differences in CO Exposure?
- Do Special Occupational Groups have Significantly High Exposures?
- Does Smoking Influence Indoor Concentrations of CO?
- On Days with High Ambient CO Levels, are Personal and Indoor Exposures Higher?

Table III. Comparison of Fixed Site CO averages with microenvironment type commuting

	CO Concentration (ppm)	
Fixed Location[28]	Morning Commute (0700-0900)	Evening Commute (1600-1800)
Washington, D.C.	2.7	3.1
Maryland (portion)	2.4	1.6
Virginia (portion)	1.8	1.8
Average Fixed Site	2.3	2.2
Microenvironment Type[19]		
Commuting - Automobile	10.3	11.3
- Bus	7.5	6.2
- Rail	2.9	2.2

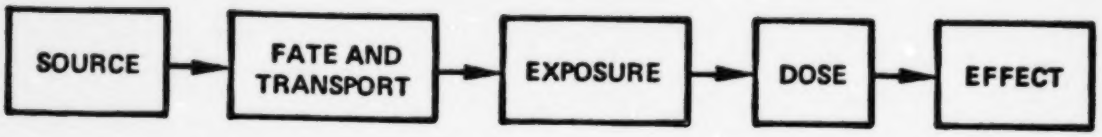

Figure 1. Components of a conceptual risk model that relates the sources of environmental pollution to ultimate effects of pollutants on the population.

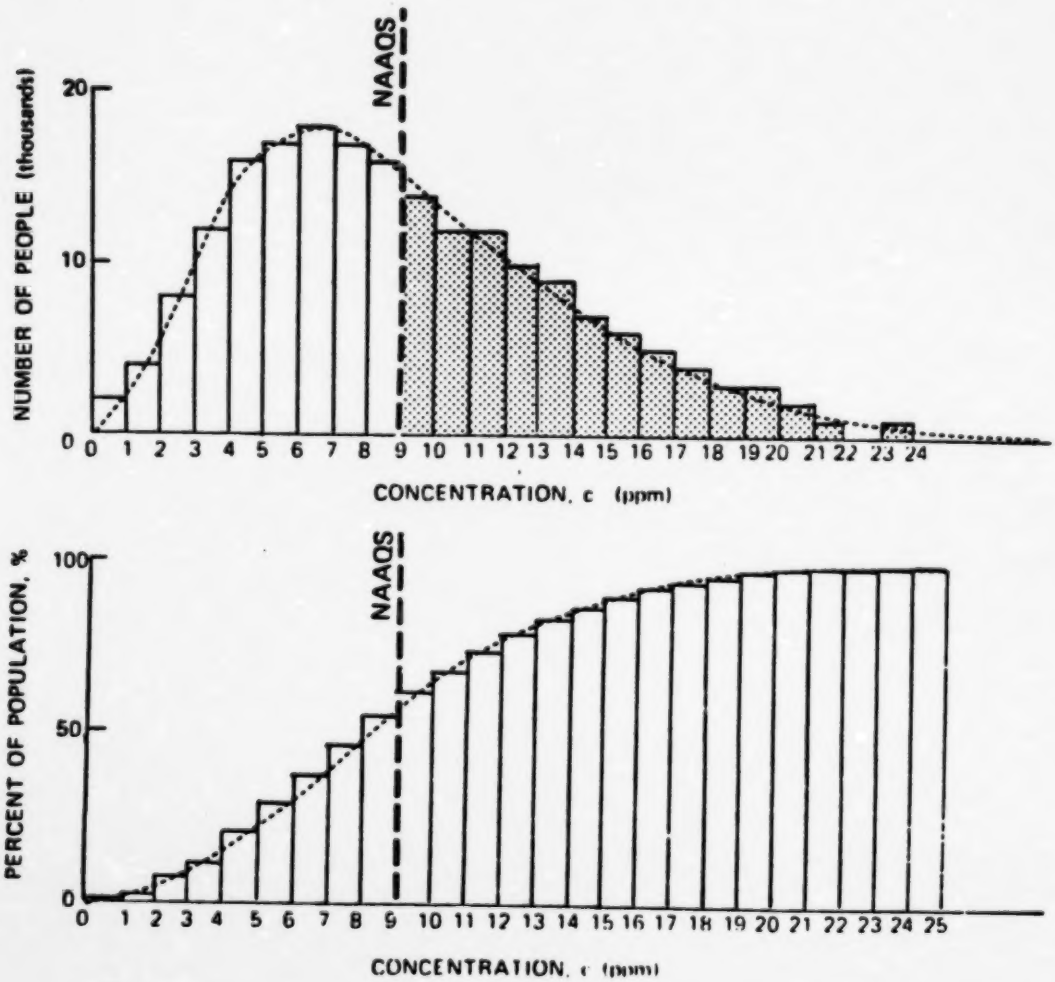

Figure 2. Hypothetical frequency distribution of exposures of a population of 200,000 persons to air pollution on a particular date showing: histogram of exposures (top), and cumulative frequencies of exposures (bottom).

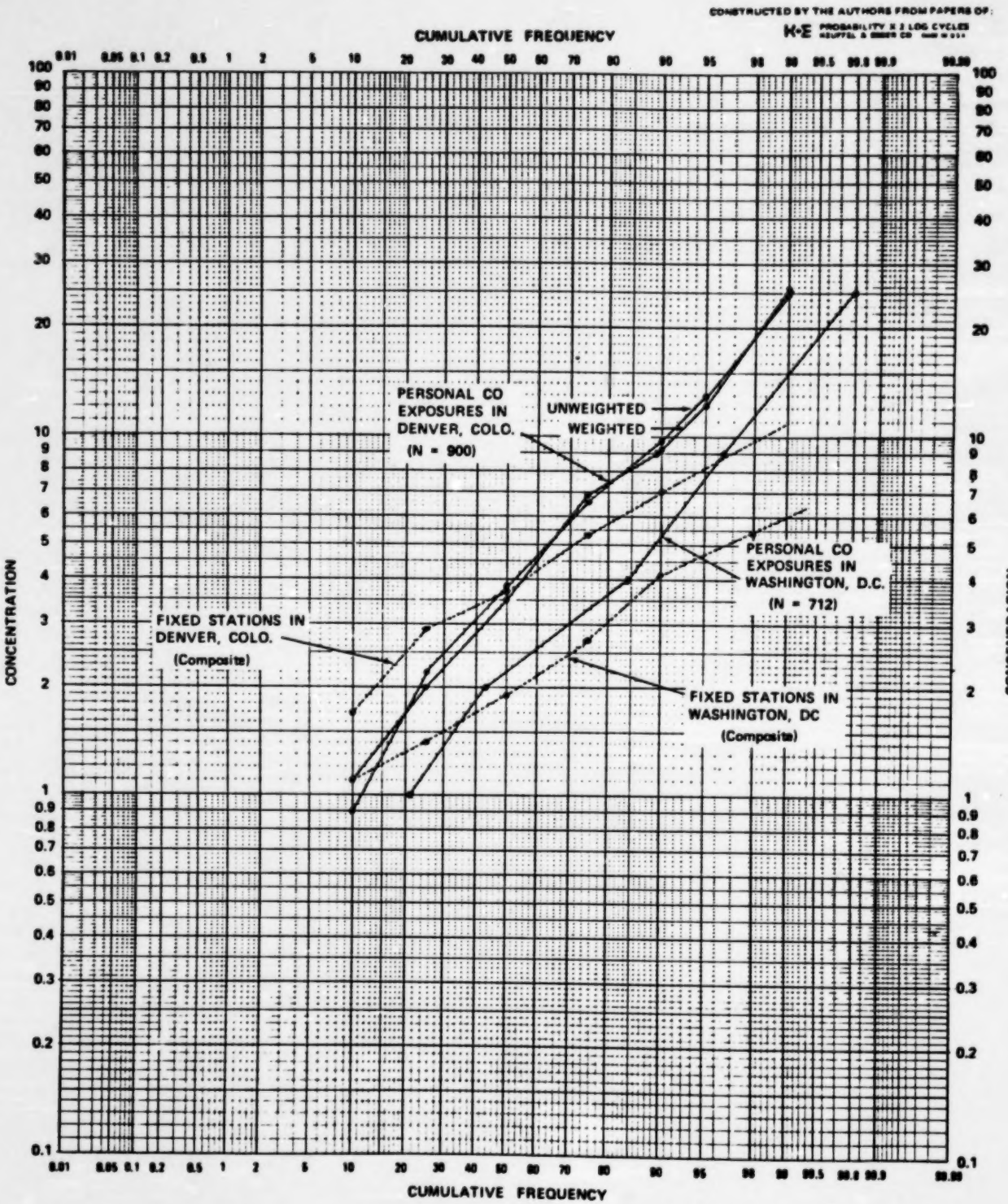
CONSTRUCTED BY THE AUTHORS FROM PAPERS OF:
CUMULATIVE FREQUENCY
CONCENTRATION
PERSONAL CO EXPOSURES IN DENVER, COLO. (N = 900)
UNWEIGHTED
WEIGHTED
PERSONAL CO EXPOSURES IN WASHINGTON, D.C. (N = 712)
FIXED STATIONS IN DENVER, COLO. (Composite)
FIXED STATIONS IN WASHINGTON, DC (Composite)
CUMULATIVE FREQUENCY
CONCENTRATION

Figure 3. FREQUENCY DISTRIBUTION OF MAXIMUM 8-HOUR CO POPULATION EXPOSURES IN DENVER, COLO., AND WASHINGTON, D.C., PLOTTED ON LOGARITHMIC-PROBABILITY PAPER, ALONG WITH 8-HOUR MAXIMUM CONCENTRATION OBSERVED AT FIXED STATIONS, NOVEMBER 1982 THROUGH FEBRUARY 1983.